Exotic dynamically generated baryons with C= −1

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Abstract. We follow a model based on the SU(8) symmetry for the interaction of mesons with baryons. The model treats on an equal footing the pseudo-scalars and the vector mesons, as required by heavy quark symmetry. The T-matrix calculated within an unitary scheme in coupled channels has poles which are interpreted as baryonic resonances.

INTRODUCTION

There is a long standing discussion on the structure of certain hadrons. Although the ground state hadrons fit quark model predictions, many excited states have properties which are no well described by these models. For these hadrons, whose structure is not well described by quark models, one appealing possibility is that they are are dynamically generated states. That means they are quasi bound states generated by the interaction of the ground state hadrons. This picture of dynamically generated states has been successful in describing numerous observed meson and baryon excited states in the charmed and non-charmed sectors.

In the present work we want to explore the possibility of generating dynamically exotic baryon states with negative charm quantum number. The possible existence of such baryons has already been investigated in [1, 2], where the interaction of pseudo scalar mesons with ground state $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons have been studied and dynamically generated states have been obtained for C=2, 1, 0 and -1. The meson baryon interaction in these works is based on chiral and SU(4) flavor symmetry and the KSFR relation. The dynamics behind the interaction is assumed to be the exchange of vector mesons in the Weinberg-Tomozawa term, while the flavor symmetry is broken by using physical hadron masses.

For our model we follow an approach consistent with heavy quark symmetry which

has been used in [3]. Heavy quark symmetry considers the fact that, for infinitely heavy quark masses, the spin interaction of quarks vanishes. In order to construct the model one mixes SU(4) flavor symmetry with the spin SU(2) symmetry and considers for the interaction the SU(8) symmetry. Pseudo scalar and vector mesons are treated on equal footing as well as $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons.

The presentation is organized as follows: in the next section we present the mathematical framework on which the SU(8) model is based and the tools needed for dynamically generating resonances by calculating the scattering T-matrix and identifying poles on it. Afterwards we present our results and comment on the differences with other works, identifying a possible candidate for a claimed experimental state. In the last section we make our conclusions.

FRAMEWORK

We follow here an SU(8) spin flavor scheme. Detailed explanations on the model can be found in reference [3]. Previously used models based on SU(4) symmetry do not include heavy pseudo-scalar and heavy vector mesons on an equal footing and this is not justified from the point of view of HQS, which is the proper spin-flavor symmetry of QCD considering infinitely heavy quark masses.

In SU(8), the lowest lying baryons are represented by a 120-plet. The 120-plet breaks into two 20-plets that accommodate the spin $\frac{1}{2}^+$ baryons and four 20'-plets that are identified with the spin $\frac{3}{2}^+$ baryons. The mesons are represented by a 63-plet plus a singlet. The SU(8) 63-plet contains one SU(4) 15-plet for the pseudo scalar mesons and three 15-plets plus three singlets that accommodate the vector mesons.

There are four possibilities to construct mesonic and baryonic hadronic currents that can couple to a singlet in order to construct a Lagrangian invariant under SU(8) rotations, but only one of these possibilities reproduces the SU(3) Weinberg-Tomozawa Lagrangian for the light mesons and baryons [3]:

$$\mathscr{L}_{WT}^{SU(8)} \propto ((M^\dagger \otimes M)_{63_a} \otimes (B^\dagger \otimes B)_{63})_1. \tag{1}$$

The reduction of this Lagrangian to SU(6) reproduces the Weinberg-Tomozawa Lagrangian used in [4].

In order to break flavor symmetry we use physical masses for the mesons and different meson decay constants:

$$f_{D_s} = 193.7 \text{ MeV}, \quad f_D = f_{D^*} = f_{D_s^*} = 157.4 \text{ MeV}. \tag{2}$$

The s-wave tree level amplitudes between two channels for each $CSIJ$ sector is given by:

$$V_{ij}^{CSIJ} = \xi_{ij}^{CSIJ} \frac{2\sqrt{s} - M_i - M_j}{4 f_i f_j} \sqrt{\frac{E_i + M_i}{2M_i}} \sqrt{\frac{E_j + M_j}{2M_j}}, \tag{3}$$

where $\sqrt{s}$ is the center of mass energy of the system, M_i is the mass of the baryon in the ith-channel, E_i is the energy of the C.M. baryon in the ith-channel, f_i is the decay constant

of the meson in the ith-channel and ξ_{ij}^{CSIJ} are coefficients coming from the SU(8) group structure of the couplings. Tables for the ξ coefficients can be found in [5].

We use this matrix V as kernel to calculate the T-matrix:

$$T^{CSIJ} \;=\; (1 - V^{CSIJ}G^{CSIJ})^{-1}V^{CSIJ}, \tag{4}$$

where G^{CSIJ} is a diagonal matrix containing the two particle propagators for each channel. Explicit expressions for the loop functions are found in [6]. With these ingredients one can calculate the T-matrix for the scattering of mesons on baryons and identify poles in it, which are interpreted as resonances.

One can also calculate the coupling of the resonance to the different channels by noting that close to a pole the T-matrix can be written as:

$$T_{ij}^{CSIJ}(z) \;=\; \frac{g_i g_j}{z - z_{pole}}, \tag{5}$$

where z_{pole} is the pole position in the $\sqrt{s}$ plane and the g_k is the dimensionless coupling of the resonance to channel k. So, by calculating the residues of the T-matrix at some pole, one obtains the product of the couplings $g_i g_j$.

RESULTS

Studying the eigen values of the ξ matrices in Eq. (3) one can know where the interaction is attractive and therefore how many resonances one might expect. A very rich spectrum is obtained in the $C = -1$ sector. The attractive SU(3) multiplets in this sector are: for $J = \frac{1}{2}$ two triplets, one $\bar{6}$-plet, two 15-plets and one 15'-plet; for $J = \frac{3}{2}$ sector one triplet, one $\bar{6}$-plet, two 15-plets and one 15'-plet and for $J = \frac{5}{2}$ only one 15-plet.

Resonances bound by energies of the order of 200-300 MeV in relation to the thresholds of their main channels are expected to be more affected by the approximations made, since our approach is based in the Weinberg-Tomozawa term of Eq. (1). This Lagrangian is roughly the first order term in a low momentum expansion, therefore, we expect theoretical uncertainties affecting our results for such states to be bigger, since higher order Lagrangians should give sizable corrections. On the other hand some of the states which we obtain are bound by 150 MeV or less [5]. Our results for such states are expected to be more precise.

Among the resonances we call the attention to the $S = 0$, $I = 0$ member of the sextet, generated by the $N\bar{D}$ and $N\bar{D}^*$ coupled channel dynamics. This state appears bound by only 1 MeV, and it is one of our more interesting predictions. Moreover, it appears as a consequence of treating heavy pseudo-scalars and heavy vector mesons on an equal footing, as required by HQS. Indeed, if one looks at the coupled channel matrix, ξ_{ij} in this sector, one finds the diagonal $N\bar{D} \to N\bar{D}$ entry is zero, which means that no resonance in this sector would be generated if the $N\bar{D}^*$ channel is not considered, as it was the case in Ref. [1].

One of the poles we obtain for $J = \frac{3}{2}$ has a mass close to 3100 MeV. There is one experimental claim for an exotic state with $C = -1$ around this mass in [7]. The state

claimed in [7] has been observed in the decay mode

$$\Theta_{\bar{C}} \quad \rightarrow \quad N\bar{D}^* \rightarrow N\bar{D}\pi, \tag{6}$$

Our dynamically generated state has other two possible decay channels induced by its coupling to channels involving the $\Delta(1232)$ resonance, which is not a stable particle. Thus, the anti-charmed resonance can decay to $\bar{D}$ or $\bar{D}^*$ plus a virtual Δ, which subsequently would decay into a πN pair. So, the dynamically generated state has now another two decay mechanisms apart from the one in Eq. (6), namely

$$\Theta_{\bar{C}} \quad \rightarrow \quad \Delta\bar{D} \rightarrow N\pi\bar{D} \tag{7}$$
$$\Theta_{\bar{C}} \quad \rightarrow \quad \Delta\bar{D}^* \rightarrow N\pi\bar{D}\pi. \tag{8}$$

The decay in Eq. (7) has the same particles in the final state that in Eq. (6), with the difference that the pion in one case is coming from the decay of the D^* and therefore has low momentum, while in the other channel it comes from a Δ and may have higher momentum. The experimental search made in [7] looked only for pions in order to reconstruct a D^* and may have missed the other events where the pion comes from a Δ.

CONCLUSIONS

We have studied the possibility of generating dynamically exotic baryon resonances with $C = -1$ from the meson baryon interaction. In order to model the meson baryon interaction we have considered an interaction kernel based on the Weinberg- Tomozawa term with SU(8) spin flavor symmetry which takes into account the heavy quark symmetry of QCD if one considers infinitely heavy quark masses. From the interaction kernel one calculates the scattering T-matrix and searches this T-matrix for poles. Poles appearing in the appropriate Riemann sheets are interpreted as resonances.

A very rich spectrum is generated by the model, but the results for many resonances should be considered with caution since they might appear strongly bound and for such states higher order corrections in the Lagrangian may affect the results.

Some of the states that one obtains from our model cannot be reproduced in models considering only the SU(4) symmetry, since these models do not treat on equal footing mesons and baryons of different spins.

One of the states obtained in the model could accommodate the experimental claim for an anti-charmed penta quark. We have showed that this state may couple to more channels than the ones observed experimentally and therefore, further investigation should help in the identification of this state.

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